Energynet® High-definition Power System Simulation

MW-Class Distribution-Connected PV
Area-Level Identification of Low-Impact Sites

NEW POWER TECHNOLOGIES

March, 2011

"…a quick and simple method to determine which DG systems can be safely interconnected with negligible risk of negatively impacting grid function."

-- solarabcs.org/FERCscreens

CEC Contract 400-07-032

Potential High-Penetration PV Grid Impacts

- **Unintended island post-fault**
- **Overloaded equipment**
- **Impacts on system protection**
- **Circuit/system voltage rise or voltage fluctuation**

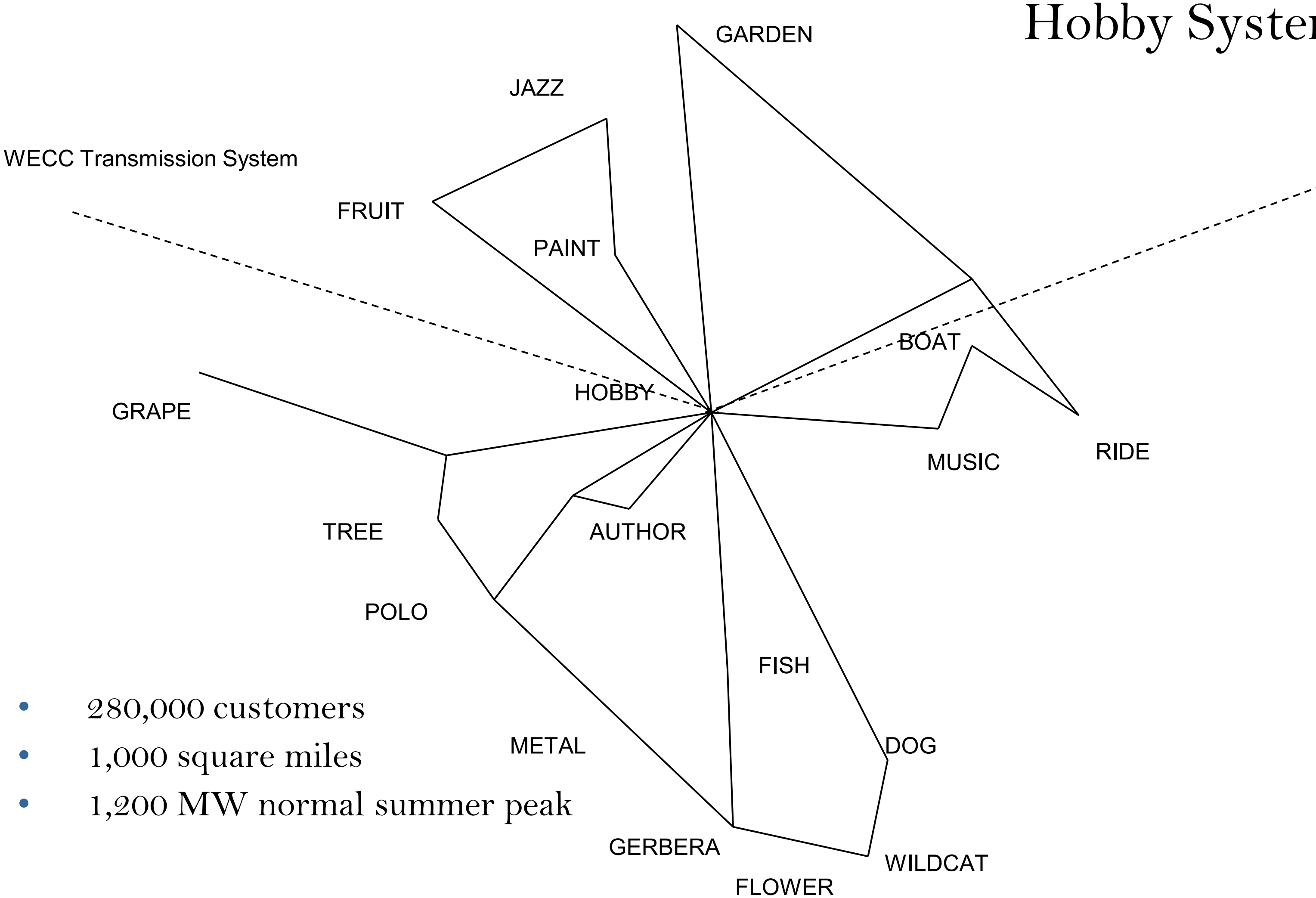
=> Each project of a particular size at a particular location has unique impacts.

Energynet Power System Simulation

- **Area-wide, integrated T&D simulation**
- **Field monitoring points fully-integrated**
- **Simulation results validated with field measurements**
- **Model produced and updated by software from raw data**

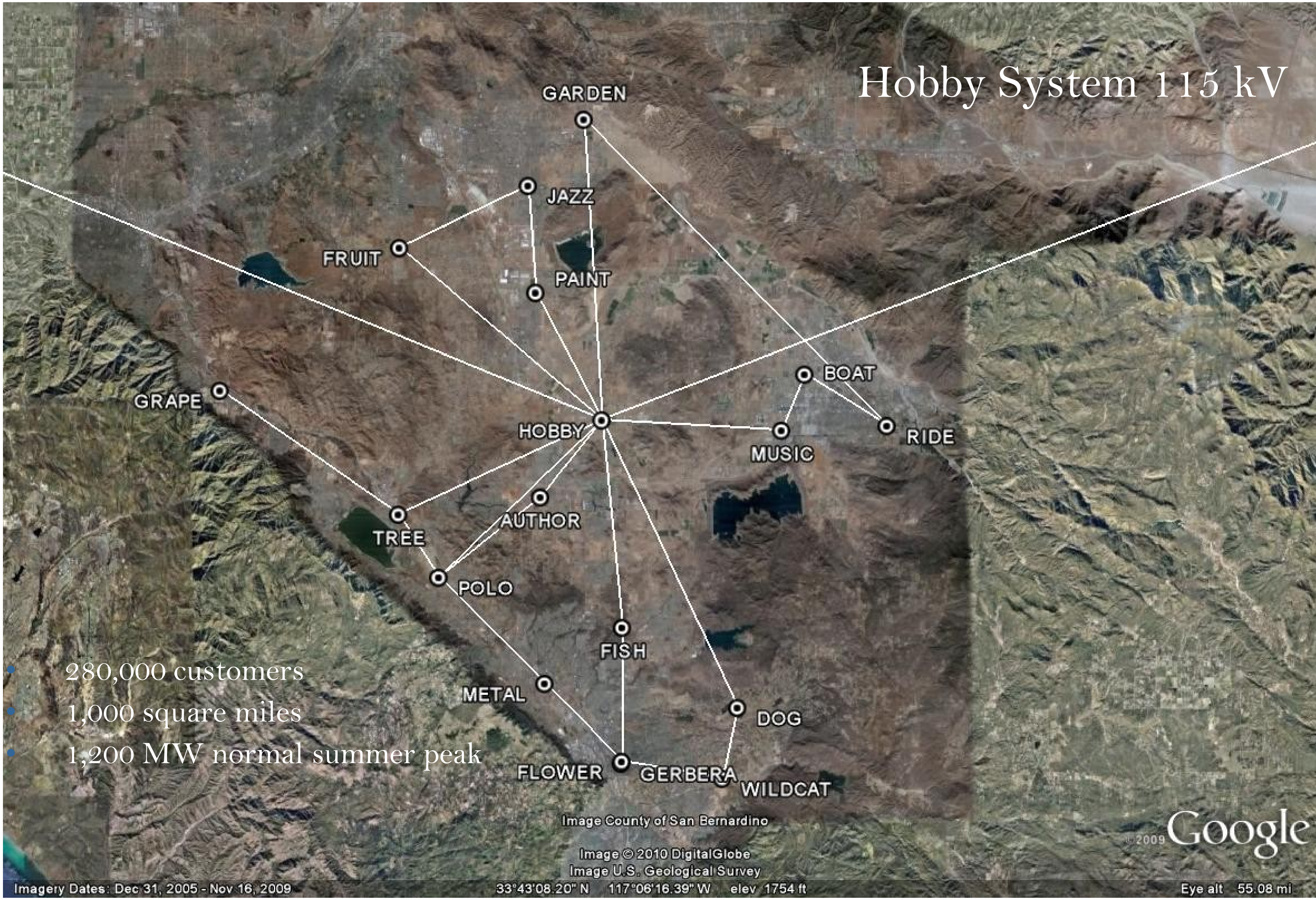
New Power Technologies, “Verification of Energynet® Methodology”, CEC 2010
http://www.energy.ca.gov/2010publications/CEC-500-2010-021/CEC-500-2010-021.PDF

Hobby System 115 kV



- 280,000 customers
- 1,000 square miles
- 1,200 MW normal summer peak

Hobby System 115 kV



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- 1,000 square miles
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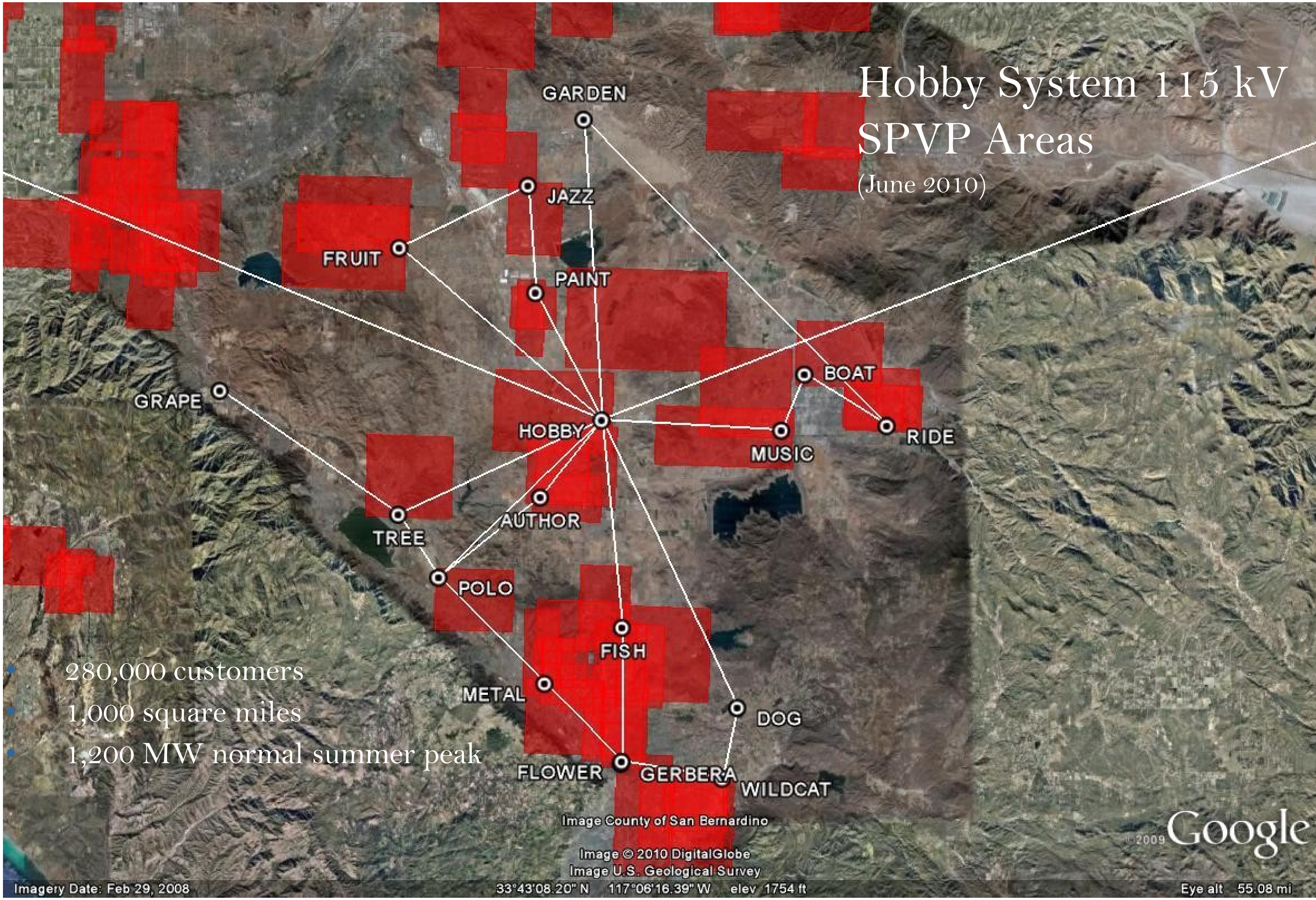
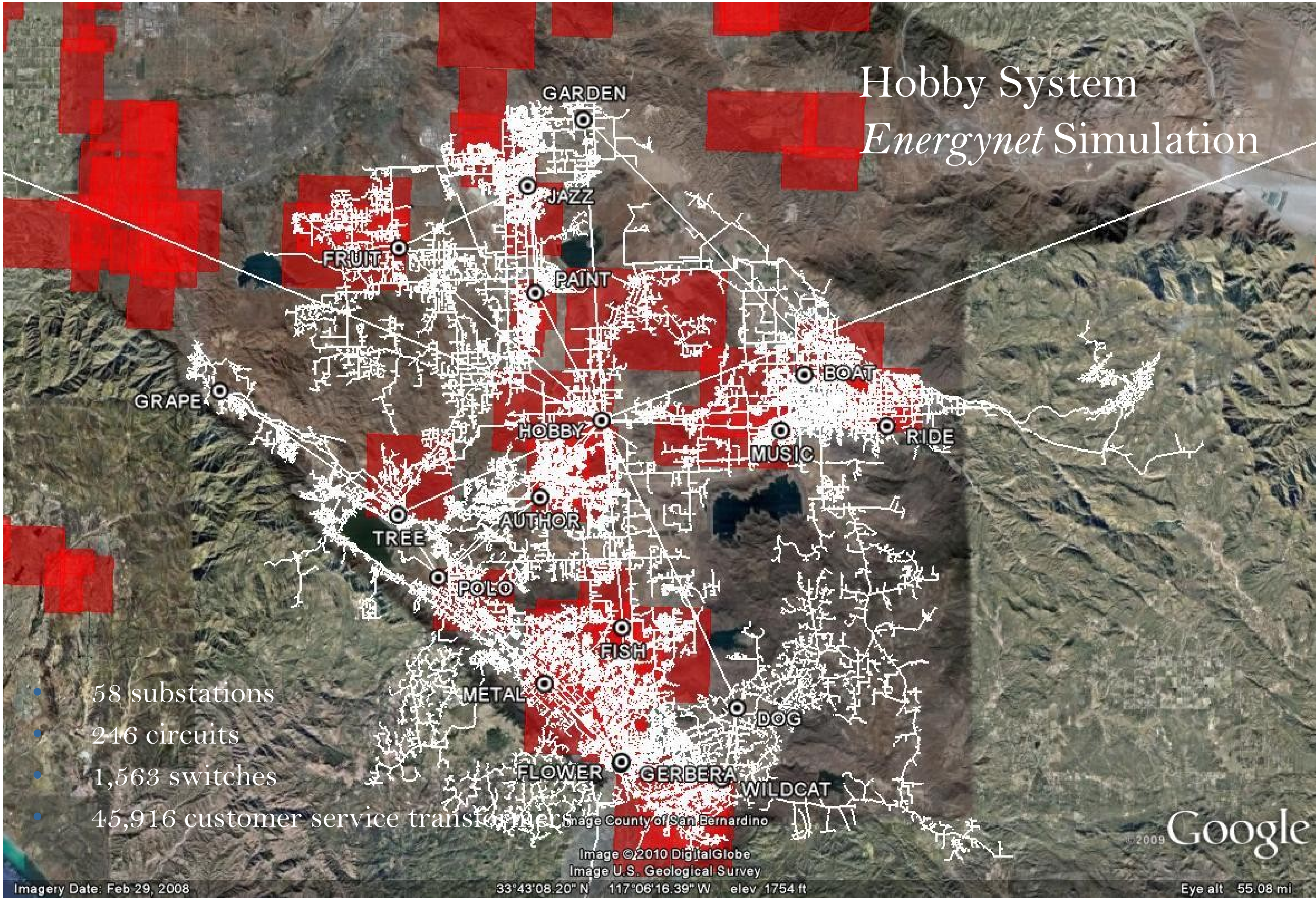
Hobby System 115 kV SPVP Areas

(June 2010)



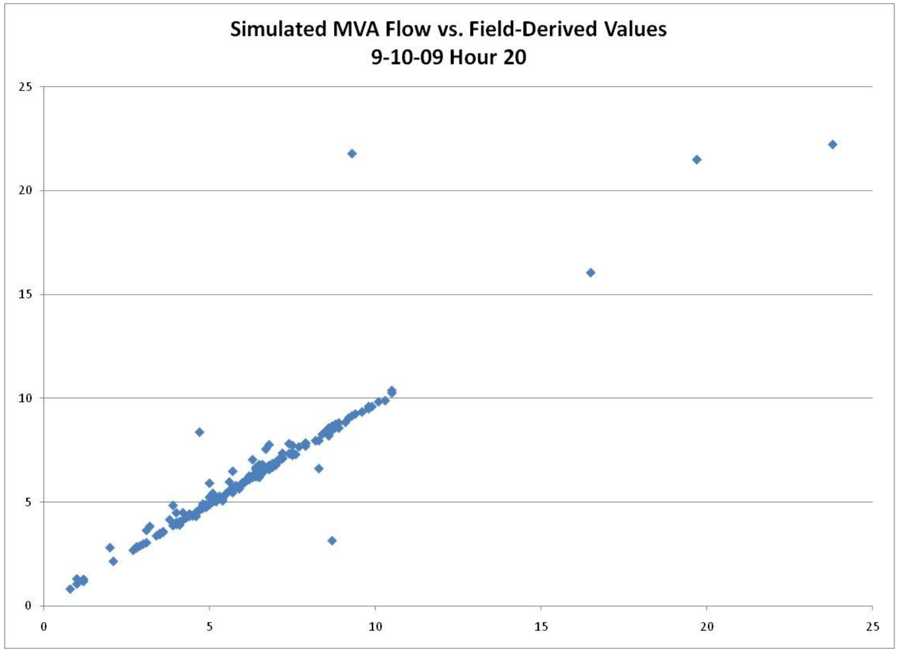
- 280,000 customers
- 1,000 square miles
- 1,200 MW normal summer peak

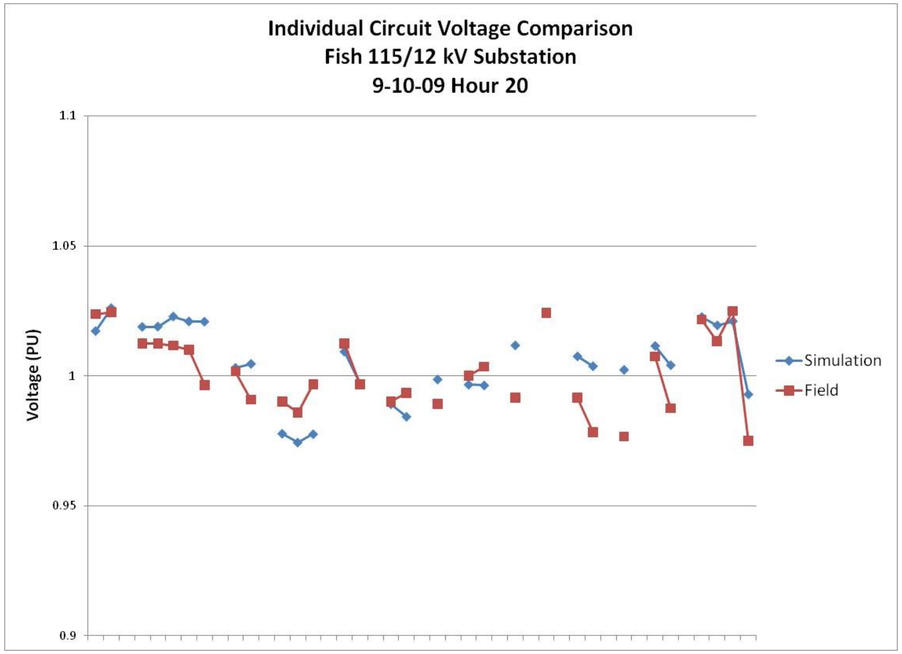
Hobby System *Energynet* Simulation



- 58 substations
- 246 circuits
- 1,563 switches
- 45,916 customer service transformers

Energynet Simulation a Validated Predictor of Actual System Conditions





- Simulation voltage results within 2% of field data reads at ~650 widely-dispersed locations
- Area model produced from raw data in one month
- Area model updated in one day using secure web file transfer

Preliminaries

- **Projects**
  - **500 kW - 5 MW in 500 kW tranches**
  - **Primary energy: solar**
  - **Interconnection: inverter**
  - **Fixed/unity power factor**
- **Eligible Sites**
  - **Distribution circuit buses representing physical system structures**
  - **33kV, 12 kV, 4.8 kV, 2.4 kV**
  - **78,468 sites in Hobby System**
- **System**
  - **Hobby system actual configuration and switch positions on September 10, 2009**
  - **Hobby system actual hourly loads and device status on September 10, 2009**
    - (a valid simulation of actual system conditions, but not indicative of low-load impacts)

Low-Impact PV Project Assessment Criteria

- **Project will not sustain a post-fault island**
  - PV incorporates anti-island scheme
  - Aggregate circuit PV < 100% of circuit minimum daytime load less existing DG
  - No single-phase interconnections
- **Project will not cause reverse flow at substation bus/voltage regulation point**
  - Aggregate circuit PV < 100% of circuit minimum daytime load less existing DG
- **Project will not contribute to phase imbalance**
  - All PVs interconnected at 3-phase
- **Project cannot overload the upstream distribution system**
  - Project output < minimum upstream line rating at project site
- **Minimal project impact on circuit voltage**
  - Circuit has voltage regulation capability (TCUL or voltage regulator and automated line capacitors)
  - Minimum "weakness" criterion – system X/R > 1.0 at project site
  - Worst-case voltage impact < 0.02 PU at project site
  - No capacitor redispatch or TCUL steps

Single Circuit Illustration

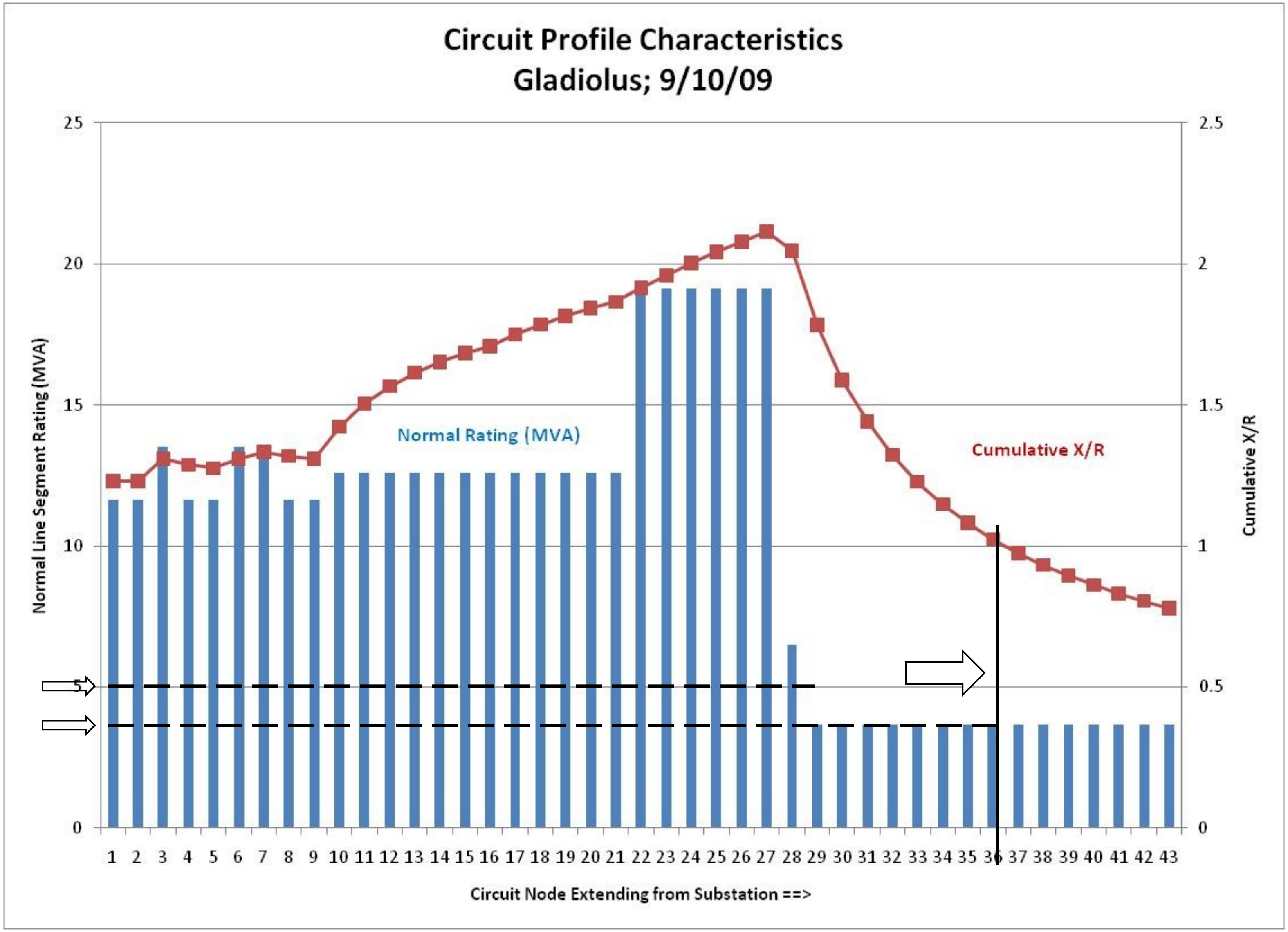
- Gladiolus Circuit (#18776)
  - 12 kV; served from Flower 115kV/12kV substation
- 352 “candidate sites” (connected physical structures)

✓ Minimum daytime load less existing DG > 5 MW
  - Maximum PV project size cannot support circuit load as an island
  - Minimum-daytime-load hour is Hour 17

✓ Substation transformer has LTC

✓ Circuit has 3 automated (voltage-controlled) line capacitors
  - Circuit has existing controls to manage possible voltage fluctuations

✓ 149 3-phase sites



Circuit Profile Characteristics
Gladiolus; 9/10/09
Normal Line Segment Rating (MVA)
Cumulative X/R
Normal Rating (MVA)
Cumulative X/R
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43
Circuit Node Extending from Substation ==>

Single Circuit Illustration (cont.)

- Gladiolus Circuit (#18776)
  - 12 kV; served from Flower 115kV/12kV substation
- 352 "candidate sites" (connected physical structures)

✓ Minimum daytime load > 5 MW
  - ➢ Maximum PV project size cannot support circuit load as an island
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✓ Substation transformer has TCUL

✓ Circuit has 3 automated (voltage-controlled) line capacitors
  - ➢ Circuit has existing controls to manage possible voltage fluctuations

✓ 149 3-phase sites

✓ **86 3-phase sites with system X/R > 1.0**

✓ **50 3-phase sites with minimum upstream line rating > 5 MW**

✓ **20 additional sites with minimum upstream line rating > 3.5 MW**

Gladiolus Circuit Individual Project Voltage Impacts

- **P5477190**
  - Maximum project size in relatively "weak" location – system X/R = 1.054
  - 5 MW project Hour 17 worst case voltage impact: 0.999 PU => 1.012 PU; Δ = 0.013 PU

- **63572007**
  - "Weak" location also limited by upstream line rating – system X/R = 1.002
  - 2.9 MW project Hour 17 worst case voltage impact: 0.995 PU => 1.006 PU; Δ = 0.011 PU

- **Neither project results in voltage out-of-spec at the PCC**
- **Neither project affects capacitor dispatch or TCUL step**
- **Neither project likely to cause voltage "sag" or "swell"**

- **P5551374**
  - 5 MW project size in an unacceptably "weak" location – system X/R = 0.780
  - Also exceeds minimum upstream line rating
  - Hour 17 worst case voltage impact: 0.994 PU => 1.024 PU; Δ = 0.030 PU

- **P5477190 and 63572007 together (7.9 MW total)**
  - P5477190 Hour 17 worst case voltage impact: 0.999 PU => 1.019 PU; Δ = 0.020 PU
  - 63572007 Hour 17 worst case voltage impact: 0.995 PU => 1.018 PU; Δ = 0.023 PU

Single Circuit Illustration (cont.)

- Gladiolus Circuit (#18776)
  - 12 kV; served from Flower 115kV/12kV substation
- 352 “candidate sites” (connected physical structures)

✓ Minimum daytime load > 5 MW
  - ➢ Maximum PV project size cannot support circuit load as an island
  - Minimum-daytime-load hour is Hour 17

✓ Substation transformer has TCUL

✓ Circuit has 3 automated (voltage-controlled) line capacitors
  - ➢ Circuit has existing controls to manage possible voltage fluctuations

✓ 149 3-phase sites

✓ 86 3-phase sites with system X/R > 1.0

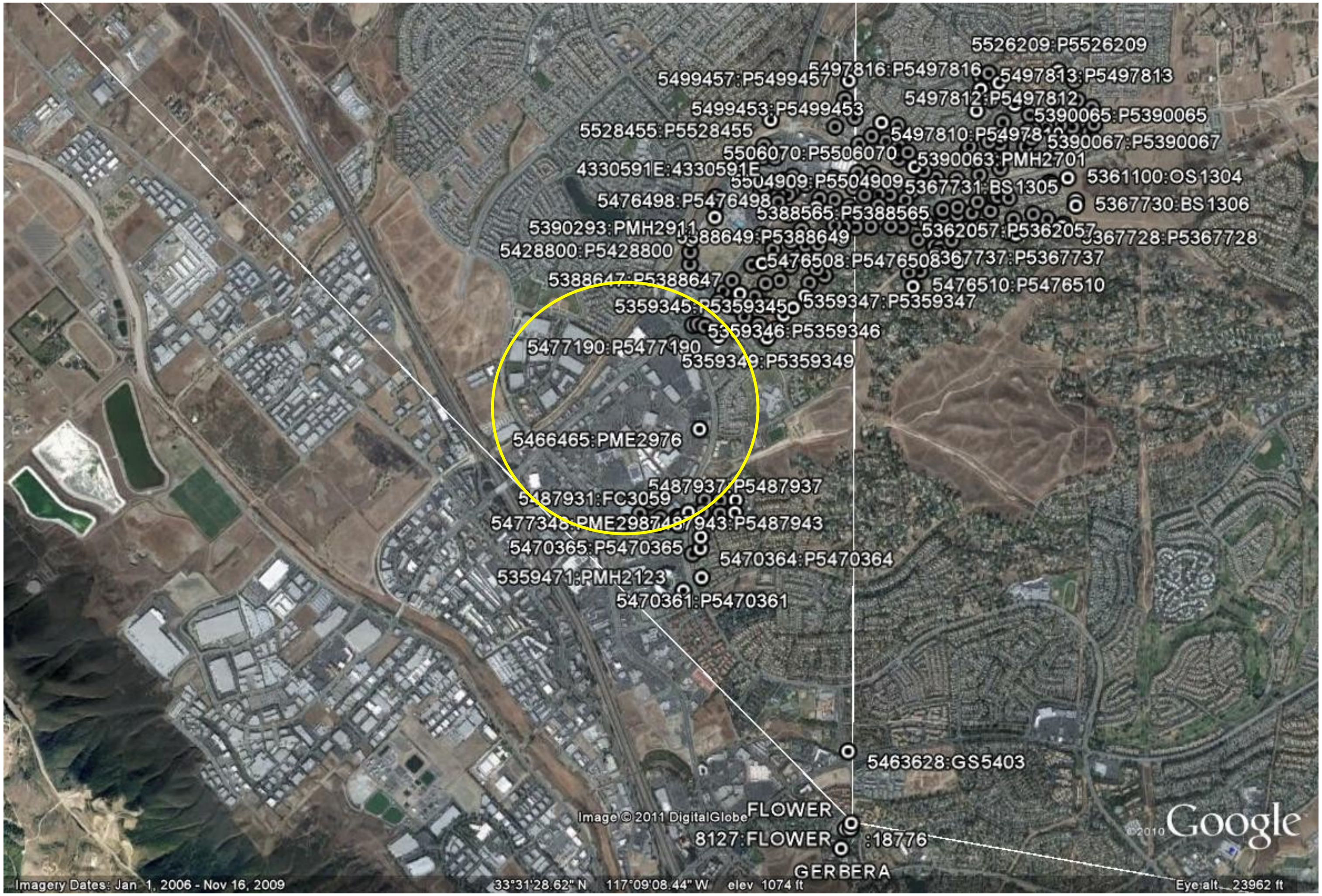
✓ 50 3-phase sites with minimum upstream line rating > 5 MW

✓ 20 additional sites with minimum upstream line rating > 3.5 MW

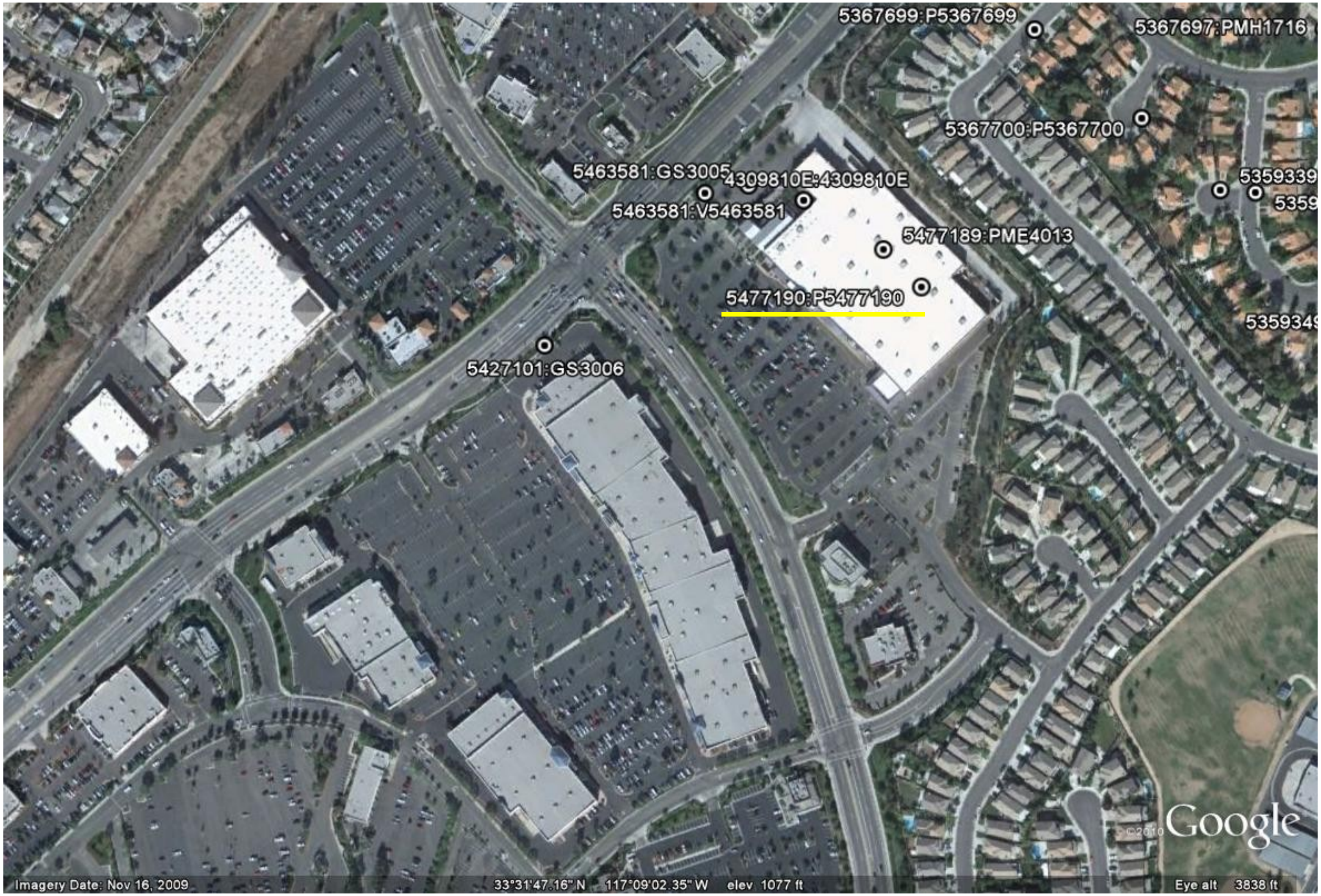
✓ **With “weakness” and line rating size limits imposed, projects at remaining eligible sites have voltage impact < 0.02 PU**

Single Site Example

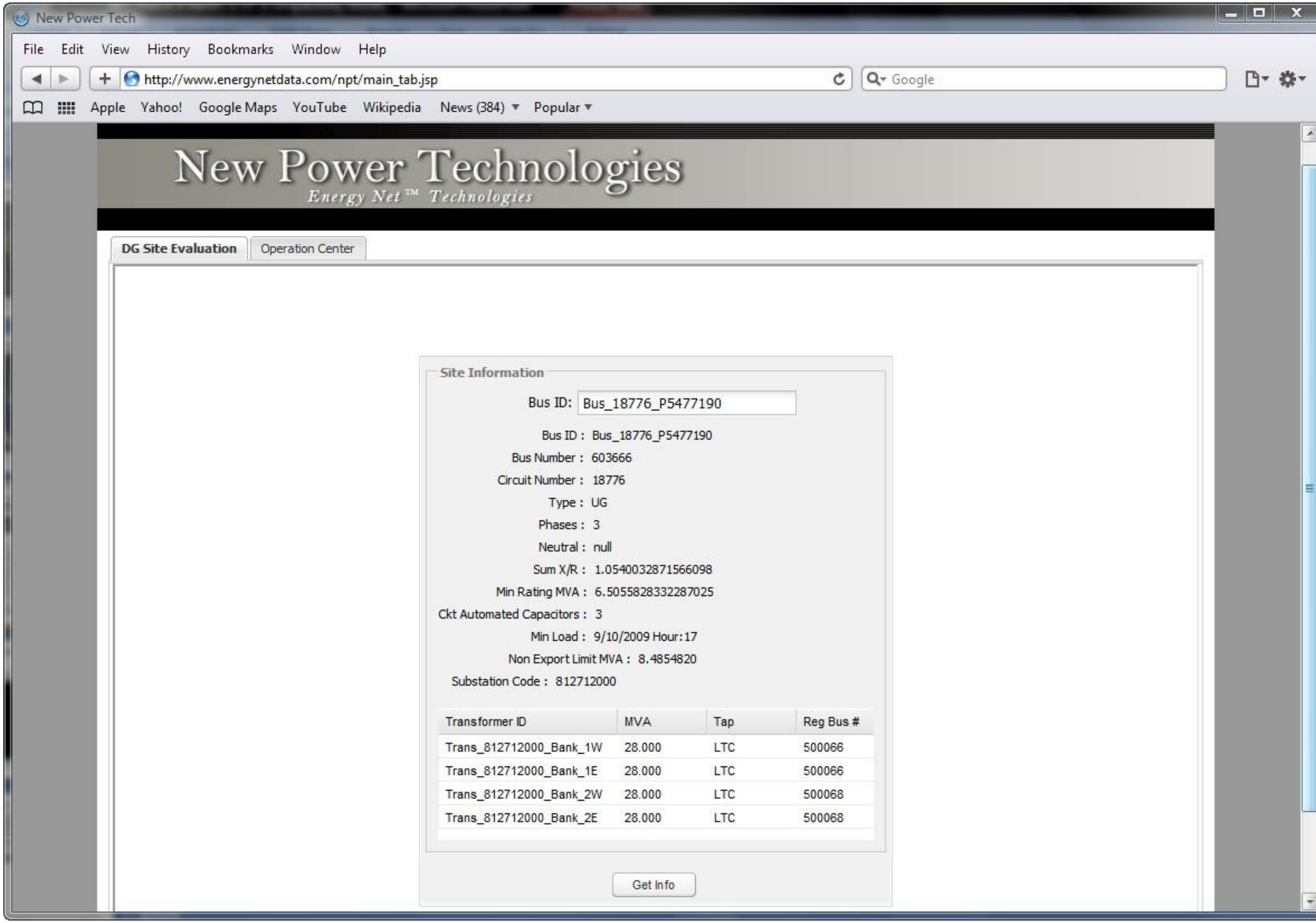
Single Site Example (cont.)



Single Site Example (cont.)

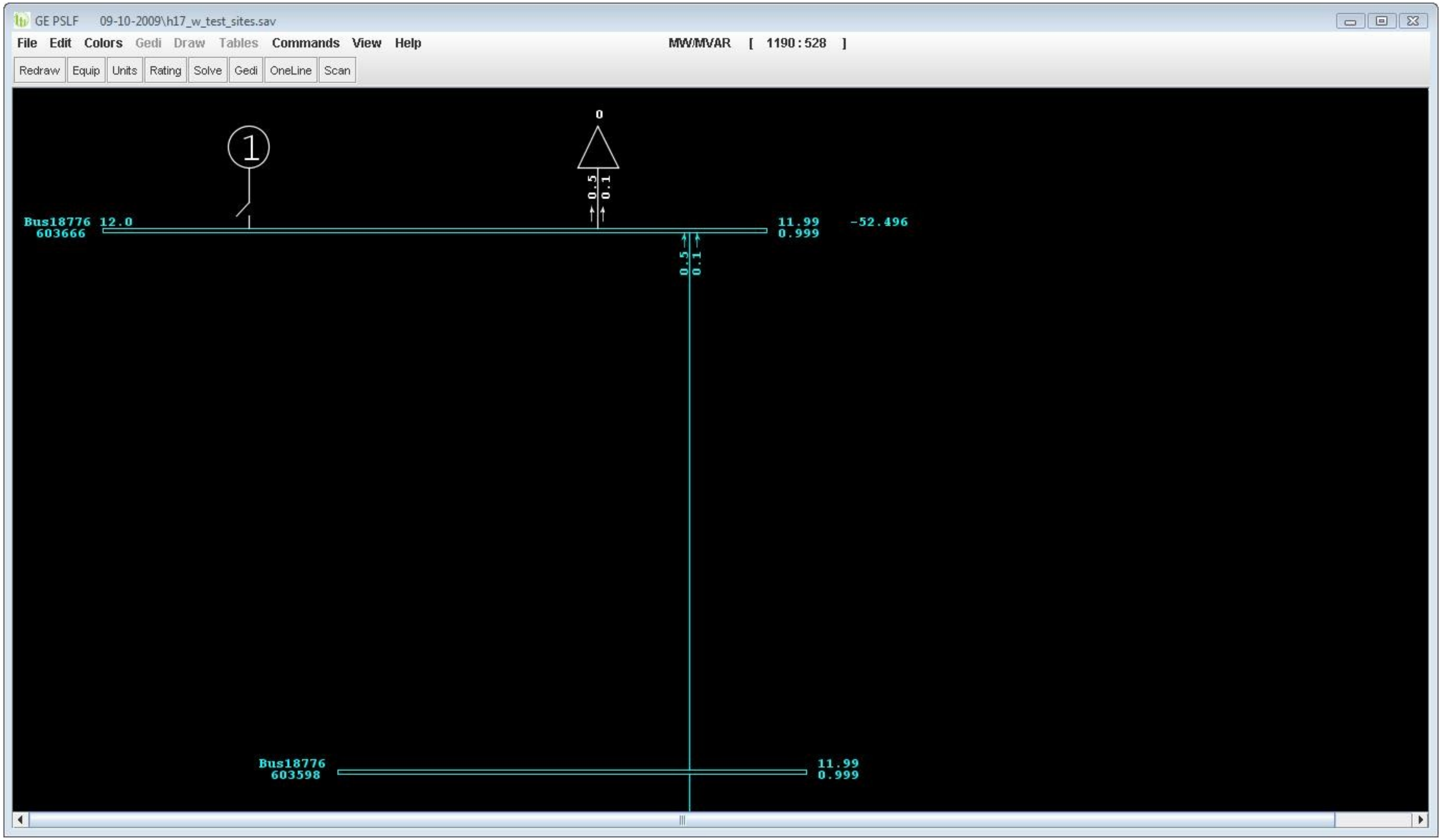


Single Site Example (cont.)



Single Site Example (cont.)

- **Voltage impact evaluation**

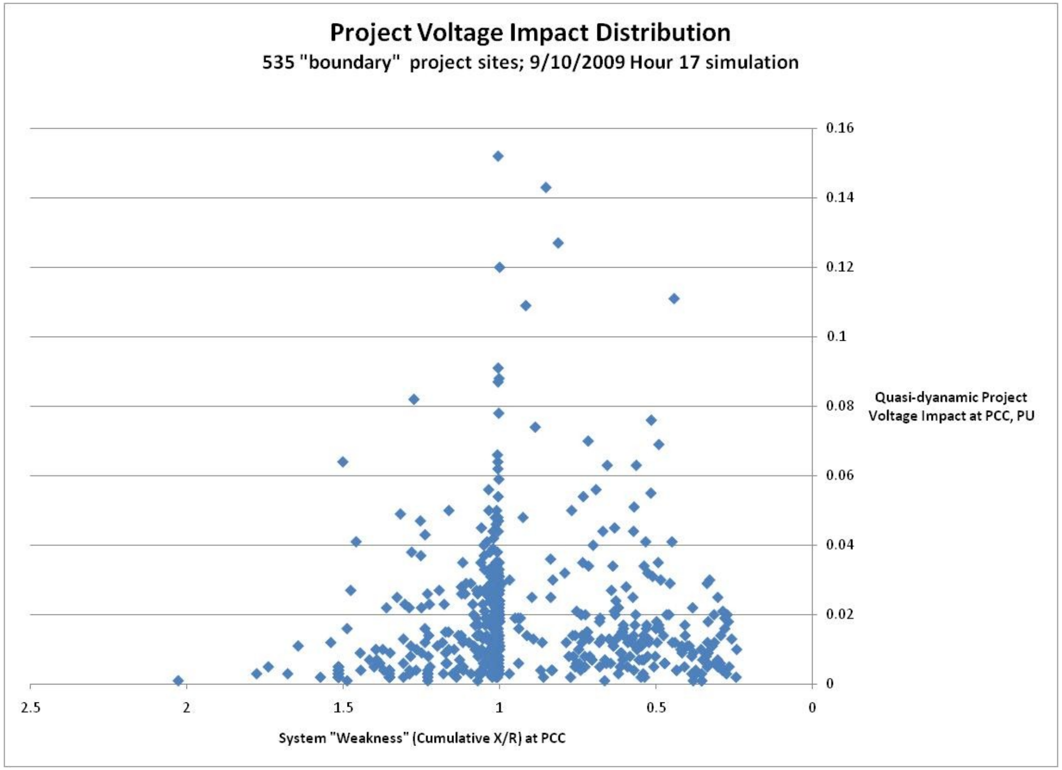


Area-wide Results

- **78,468 buses representing physical distribution system structures**
- **24,186 3-phase sites in 246 circuits**
  - Excludes substations, voltage regulators, and circuit breakers
- **17,262 3-phase sites (71%) meet "weakness" criterion (system X/R at site > 1.0)**
  - **4,683 sites (27%) where minimum upstream line rating is more limiting than non-reverse-flow.**
  - **3,754 sites (21%) lack existing voltage regulation capability (substation LTCs and circuit automated line capacitors).**

Area-wide Results (cont.)

- 60% of circuits' "boundary" projects have ΔV< 0.02 PU at system X/R > 1.00.
- 95% of circuits' "boundary" projects have ΔV< 0.035 PU at system X/R > 1.05.
- 12 circuits are unusually voltage-sensitive.



Area-wide Results (cont.)
Sites Meeting All Low-Impact Criteria

- 27 circuits with sites qualifying for up to 5 MW projects
- 12 circuits with sites qualifying for up to 4.5 MW projects
- 7 circuits with sites qualifying for up to 4 MW projects
- 10 circuits with sites qualifying for up to 3.5 MW projects
- 12 circuits with sites qualifying for up to 3 MW projects
- 10 circuits with sites qualifying for up to 2.5 MW projects
- 8 circuits with sites qualifying for up to 2 MW projects
- 5 circuits with sites qualifying for up to 1.5 MW projects
- 8 circuits with sites qualifying for up to 1 MW projects
- 5 circuits with sites qualifying for up to 0.5 MW projects
- 143 circuits with no qualifying sites

Low-Impact PV Project Assessment Criteria

- ✓ **Project will not sustain a post-fault island**
- ✓ **Project will not cause reverse flow at substation bus/voltage regulation point**
- ✓ **Project will not contribute to phase imbalance**
- ✓ **Project cannot overload the upstream distribution system**
- ✓ **Minimal project impact on circuit voltage**
  - Existing voltage regulation capability
  - "Weakness" (system X/R at site)
  - Direct project voltage impact assessment (simulation)
- ➢ **Are some more likely than others to trigger costly upgrades?**

Ideas from Energynet Validation Project

- **Use area-wide all-circuit hourly current + power factor data to determine circuits' annual minimum daytime loads**
  - Hobby system has continuous current and power factor monitoring on every circuit
- **Use legacy packet radio network, DCMS, and data management system for low-cost DG operating condition and output monitoring.**

Ideas from IEEE 1547 Working Groups

- **Inverter "power factor schedule" to dampen any voltage impacts of fluctuating DG output. (PEPCO, others)**
- **Employ low-speed, low-cost transfer trip with slow reclosing times (~ 5 sec) on circuits with high penetration DG. (Russ Neal)**

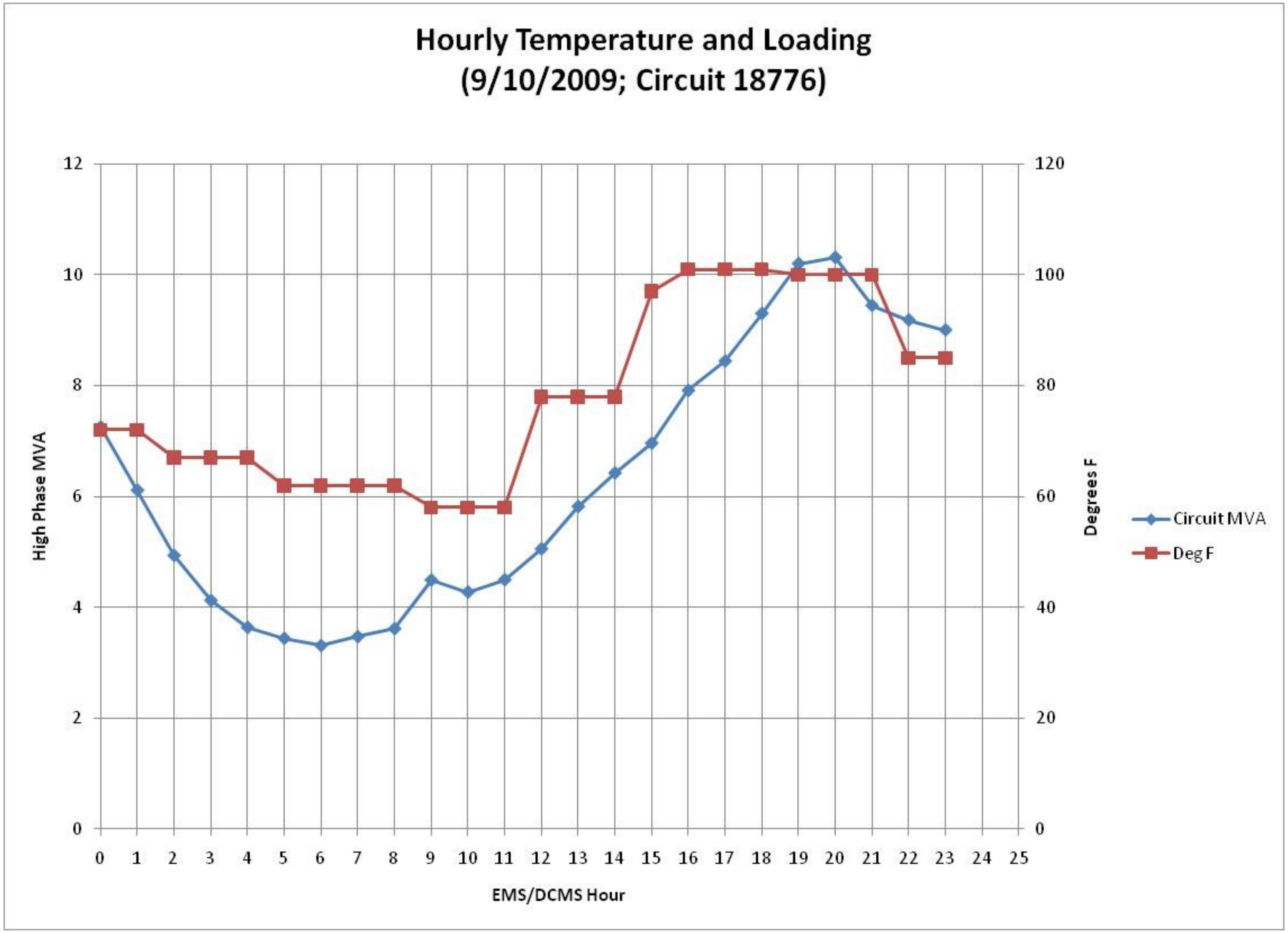
Conclusions

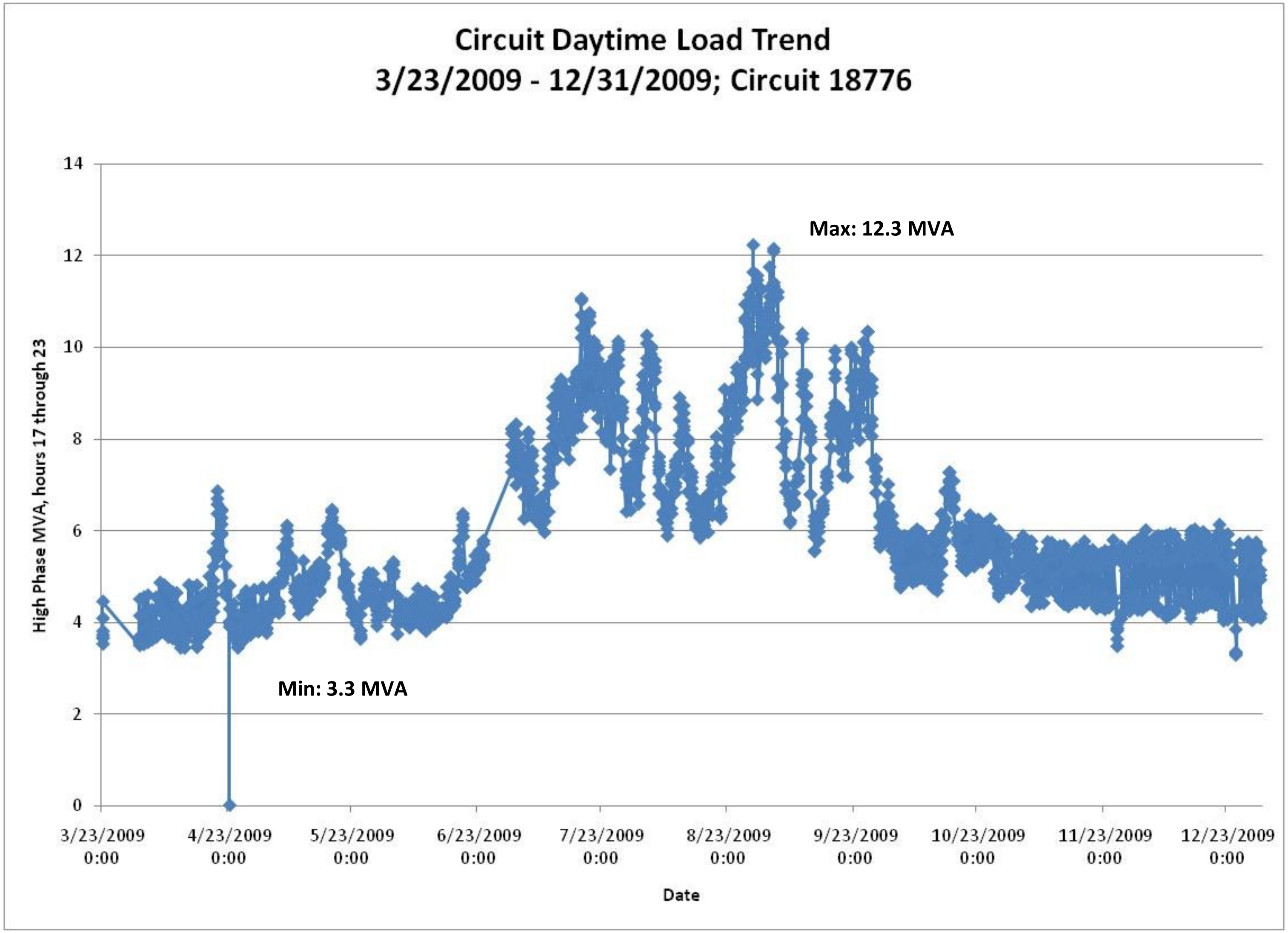
- **There is not a single project screen that works for all circuits.**
- **Project impacts differ at sites within a single circuit.**
- **PV intermittency-related voltage impacts are minimal and manageable at "strong" project sites.**
- **Individual low-impact projects may have low collective impacts (requires further study).**
- **A detailed system simulation can reveal a) site-specific system limitations and b) voltage impacts for a proposed project in a preliminary evaluation.**
- **Direct project impacts identified in a preliminary evaluation will inform a full impact study if required.**

Supplemental Slides

FERC SGIP Fast Track Screens

1. PCC on portion of Area EPS subject to tariff
2. Aggregate generation ≤ 15% of line section annual peak load
3. Aggregate inverter-based generation ≤ 5% of spot network load or 50 kW
4. Contributes ≤ 10% to maximum fault current at PCC
5. No protective device exceeds 87.5% of short-circuit interrupting capability
6. Correct type of connection to the primary distribution
7. Aggregate generation on single-phase shared secondary ≤ 20 kW
8. Imbalance between the two sides of the 240-volt service ≤ 20% of service transformer nameplate
9. ≤ 10 MW for transmission-side interconnection where there are known transient stability limitations
10. Construction would not be required by the utility


Hourly Temperature and Loading
(9/10/2009; Circuit 18776)
High Phase MVA
Degrees F
EMS/DCMS Hour
Circuit MVA
Deg F
0
2
4
6
8
10
12
20
40
60
80
100
120
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25


Circuit Daytime Load Trend
3/23/2009 - 12/31/2009; Circuit 18776
Max: 12.3 MVA
Min: 3.3 MVA
High Phase MVA, hours 17 through 23
0
2
4
6
8
10
12
14
3/23/2009 0:00
4/23/2009 0:00
5/23/2009 0:00
6/23/2009 0:00
7/23/2009 0:00
8/23/2009 0:00
9/23/2009 0:00
10/23/2009 0:00
11/23/2009 0:00
12/23/2009 0:00
Date

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New Power Technologies is dedicated to moving advanced energy technologies from theory to practical application. The company's *Energynet*® technologies enable power delivery network analysis and management with unprecedented transparency, precision, and ease of integration to support high-performance and high-efficiency network operation and planning.

Peter Evans, President of New Power Technologies, has extensive professional experience with electric power generation, delivery, and use, as well as power marketing, plant engineering, corporate and project finance, and energy technology commercialization, having held executive positions at Catalytica Energy Systems, Inc., Enron Capital & Trade Resources Corp., US Generating Company, and PG&E. Mr. Evans serves on the IEEE P1547.7 and P1547.8 working groups and the NIST Smart Grid Interoperability Panel. Mr. Evans holds BS degrees in Chemical and Nuclear Engineering and an MBA from the University of California at Berkeley. Mr. Evans holds U.S. Patents in distributed energy resources and power system analysis. He is a Professional Mechanical Engineer in California and a Chartered Financial Analyst.

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